Uncertainties of L measurement at the Tevatron

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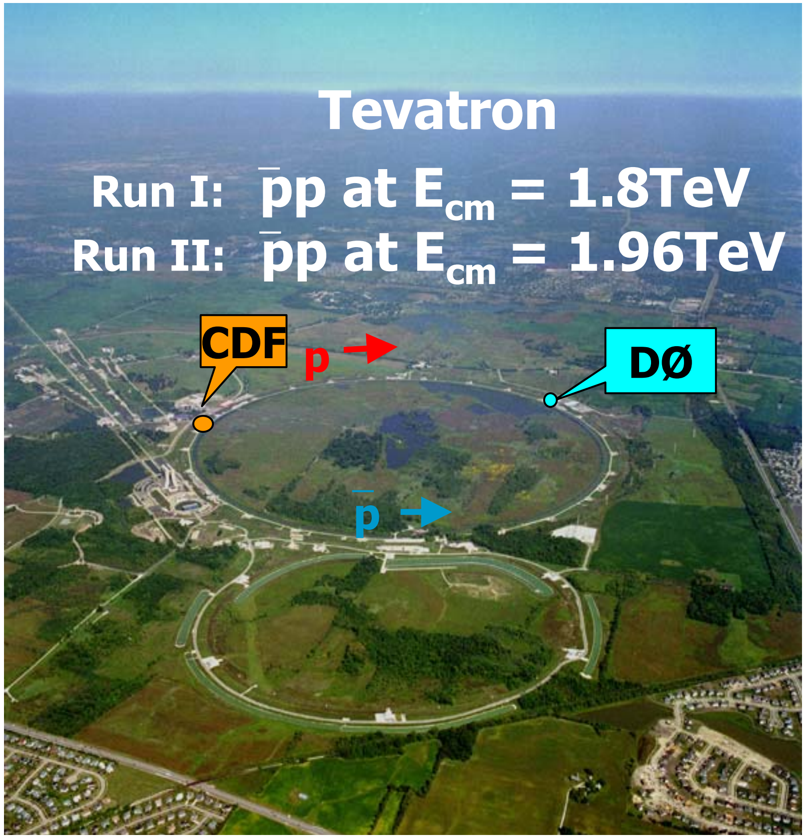
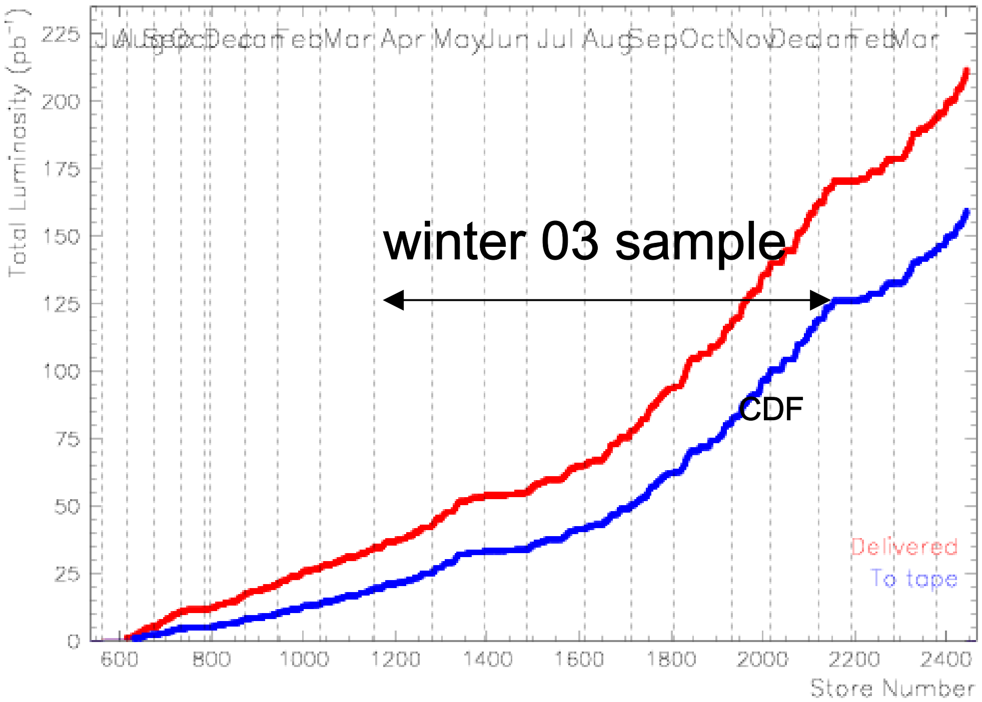
- Tevatron Luminosity
- Reference process
  - Inelastic ppbar scattering
    - ✓ Problem with the value of the inelastic x-section
    - ✓ Analysis of the CDF and E811 measurements
    - ✓ Average inelastic x-section
  - W/Z production
- Summary

Tevatron Luminosity in Run II





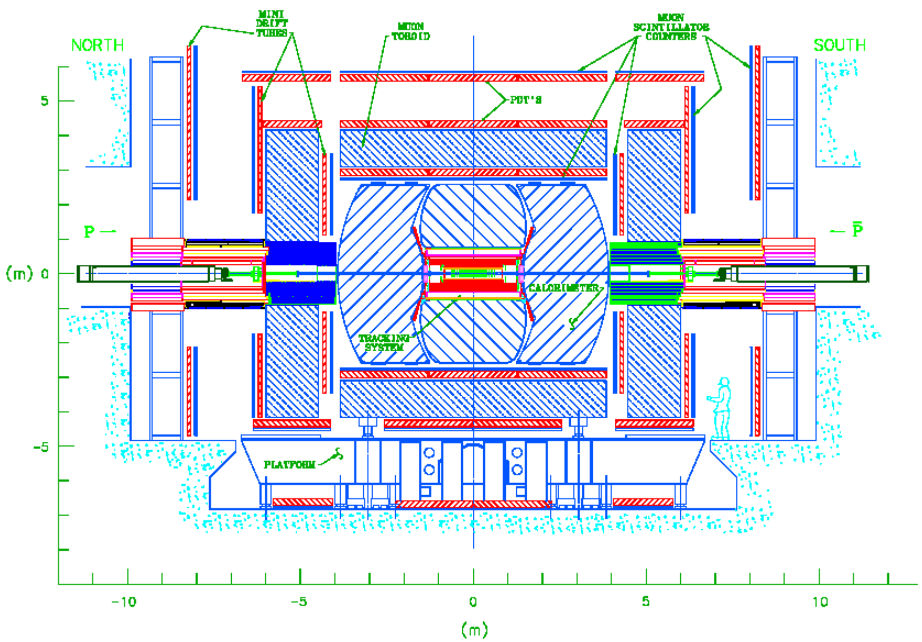
Current peak Luminosity ~$4 \cdot 10^{31} cm^{-2} sec^{-1}$

S.Klimenko CTEQ 05/02/03 Fermilab

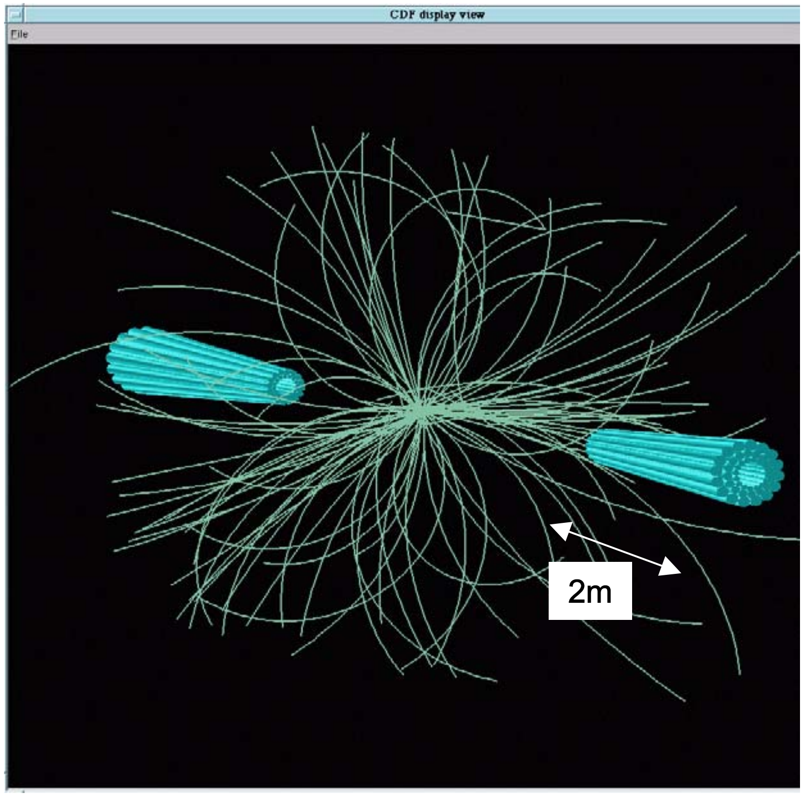
CDF & D0

- L uncertainty is one of dominant systematic errors for measurement of x-sections.

DØ



CDF



Reference process: inelastic PPbar scattering

- Luminosity measurement

$$R_{pp} = \mu_{pp} \cdot f_{BC} = \sigma_{inel} \cdot \varepsilon_{pp} \cdot \delta(L) \cdot L$$

σ_{LM}

L – luminosity
f_{bc} – Bunch Crossing rate
μ_a – # of pp / BC

σ_{inel} – inelastic x-section
ε_{pp} – acceptance for a single pp
$\delta(L)$ – detector non-linearity

- CDF established uncertainties

  ε_{pp}(4%) and R_{pp} (1.8%)

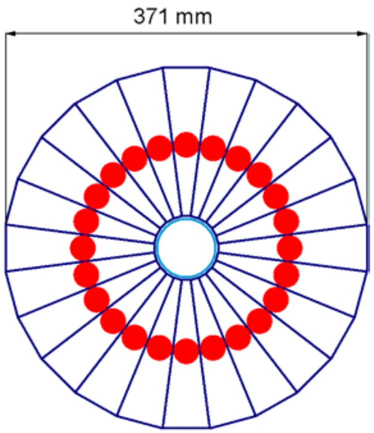
- What is uncertainty on the inelastic x-section?
  - In Run I CDF used the CDF measurement of σ_{in}.
  - DØ used the average of CDF, E811 and E710 measurements.

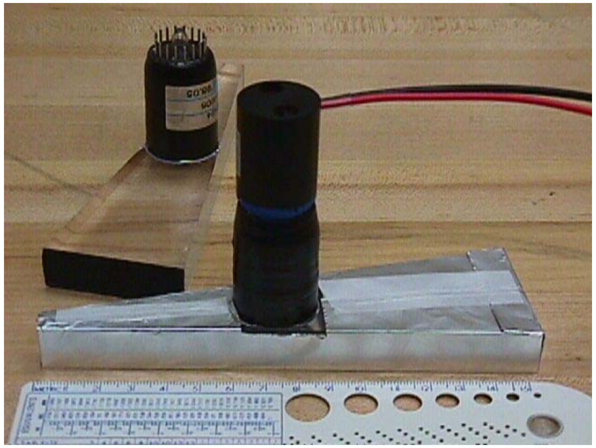
Measurement of inelastic rates

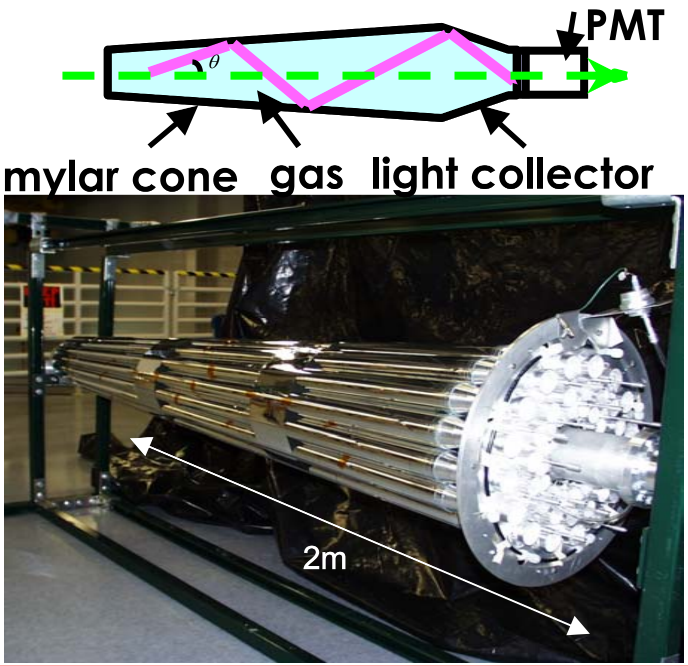
- Standalone L monitors @ small angles
- Large acceptance (~97% for HC ppbar)

CDF Cherenkov counters

DØ scintillating counters







CDF Luminosity Uncertainty

Systematic error	2 layers
CLC acceptance (2 layers):	4.0 %
Geometry & material	3.0 %
Event generator	2.0 %
Beam	1.0 %
CLC simulation	1.0 %
amplitude calibration	1.0 %
Detector stability	1.0 %
Online → offline transfer (accounting)	~ 0 %
Luminosity method	1.0 %
Losses	<1.0 %
TOTAL	4.4%

The error due to uncertainties in the inelastic x-section is not quoted.

inelastic Ppbar x-section

- L independent measurement of total PPbar x-section

$$(1+\rho^2)\cdot\sigma_{tot} = 16\pi(\hbar c)^2 \frac{dN_{el}/dt|_{t\to 0}}{N_{el}+N_{inel}}$$

ρ=0.135

- Inelastic cross-section @ 1.8TeV
  - ✓ *55.50 ± 2.20* **mb** **(E710: Phys.Rev.Let, 68, p2433, 1992)**
  - ✓ *60.33 ± 1.40* **mb** **(CDF: Phys.Rev.D, 50, p5550, 1994)**
  - ✓ *55.92 ± 1.19* **mb** **(E811: Phys.Let.B, 445, p419, 1999)**

measured using the optical theorem, along with the total & elastic x-sections

What σ_{inel} to use? Run I: CDF(BBC), DØ($\overline{\text{world}}$); Run II $\overline{\text{(CDF\&E811}}$?)

What is the error for σ_{inel}? CDF&E811 combined: ~4%

→ “poor agreement” between all three measurements.
→ For Run II CDF & **DØ do not quote the error associated with** σ_{inel} yet
→ **Joint committee is working on this issue**

Do CDF and E811 disagree?

- σ_{in}(CDF) and σ_{in}(E811) are compatible at 2.3σ.

$$\sigma_{tot} = 16\pi(hc)^2 \frac{b}{1+\rho^2} \frac{N_{el}}{N_{el}+N_{in}} \qquad b = \frac{1}{N_{el}} \frac{dN_{el}}{dt}\Big|_{t\to 0}$$

$$\sigma_{in} = 16\pi(hc)^2 \frac{b}{1+\rho^2} \frac{N_{el}N_{in}}{(N_{el}+N_{in})^2} = 16\pi(hc)^2 \frac{b}{1+\rho^2} \frac{R}{(1+R)^2}$$

- E811 used the same value of b
- Therefore compare the ratio of the inelastic and elastic rates

	CDF	E811
N_{el}	78691 ± 1463	$508.1\text{K} \pm 3.5\text{K}$
N_{in}	240982 ± 2967	$1799.5\text{K} \pm 57.2\text{K}$
R	3.062 ± 0.068	3.542 ± 0.113
b	16.98 ± 0.25	16.98 ± 0.22

- Discrepancy for R at 3.6 standard deviations!

"Single diffractive rate problem"

- **Rates measured by CDF:**

  a) elastic-N_{el}, b) double_arm-N_2 c) single_arm X p - N_{sd}

- **Rates measured by E811:**

  a) elastic-N_{el}, b) double_arm-N_2 c) single_arm - N_1

$$x = \frac{N_2}{N_{el}}, \qquad y = \frac{N_1}{N_{el}}, \qquad R = x + y$$

, , .

	CDF	E811
x	2.638 ± 0.058	2.657 ± 0.023
y	0.424 ± 0.021	0.885 ± 0.115

"obvious" conclusion: "E811 measures too many single diffractive events".
Why? "E811 has a background of 93% in single arm rate. Quite possible it was incorrectly estimated"
wrong conclusion, because CDF and E811 detector acceptances are different

What is the problem?

- Need to compare the number of "non-diffractive" and single diffractive events corrected for acceptances.

$$\varepsilon_2(CDF) \approx 98.7\%, \qquad \varepsilon_2(E811) = 88.85 \pm 2.0\%$$

- The E811 single-arm rate had a lot of "non-diffractive" events missed by the two-side inelastic trigger

$$N_{nd} = N_2 / \varepsilon_2, \quad N_{sd} = N_2\left(r + \delta - \frac{1-\varepsilon_2}{\varepsilon_2}\right).$$

r and δ were measured in a special run

	CDF	E811
N_{nd}	203200 ± 2558	$1519.7\text{K} \pm 34.9\text{K}$
N_{sd}	37782 ± 1770	$279.8\text{K} \pm 36.3\text{K}$
N_{nd}/N_{el}	2.582±0.058	2.991±0.069
N_{sd}/N_{el}	0.480±0.029	0.551±0.072
N_{sd}/N_{nd}	0.186±0.009	0.184±0.024

Conclusion: the CDF and E811 single diffractive rate seems to be consistent. We can't isolate the problem.

How to average the x-section?

- **To average two incompatible measurements X_1 and X_2 we have to ignore the accurate error analysis done by both experiments and inflate the systematic error.**
- **Procedure:**
  - **Find average value:** $$\bar{R} = fX_1 + (1-f)X_2$$
    by minimization of its variance: $$\mathrm{var}(\bar{X}) = FCF^T, \quad F = (f, 1-f)$$
    covariance matrix: $$C = \begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2\alpha \\ \sigma_1\sigma_2\alpha & \sigma_2^2 \end{bmatrix}$$
  - **Calculate $\chi2$:** $$\chi^2 = \sum \frac{(X_i - \bar{X})}{\sigma_i} C_{ij}^{-1} \frac{(X_j - \bar{X})}{\sigma_j}$$
  - **If $\chi2$ indicates disagreement → inflate the average variance**

$$\mathrm{var}(\bar{X}) \Rightarrow \mathrm{var}(\bar{X}) \cdot \chi^2$$

Averaging of R

- **Average R and calculate x-sections using** $\sigma_{in} = 16\pi(hc)^2 \frac{b}{1+\rho^2}\frac{\overline{R}}{(1+\overline{R})^2}$

- **Method A: ignore correlation between *b* and *R* → α=0.**

average R = 3.19 ± 0.06, χ2 = 13.2 → average R = 3.19 ± 0.21

$$\overline{\sigma}_{in} \cdot (1+\rho^2) = 60.4 \pm 2.3mb$$

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- **Method B: estimate α from simulation assuming gaussian errors and**

$$R = \frac{N_{in}}{n_{el}}\left(\exp\left(-bt_{\min}\right) - \exp\left(-bt_{\max}\right)\right)$$

α=-0.09, average R = 3.20 ± 0.06, χ2 = 12.3 → average R = 3.20 ± 0.20

$$\overline{\sigma}_{in} \cdot (1+\rho^2) = 60.3 \pm 2.2mb$$

Averaging of x-sections itself

	CDF	E811
Quoted σ_{tot}, *mb*	80.03 ± 2.25	71.71 ± 2.02
Derived $\sigma_{tot}(R,b)$ *mb*	80.03 ± 2.17	71.70 ± 1.90
Quoted σ_{in}, *mb*	60.33 ± 1.40	55.92 ± 1.19
Derived $\sigma_{in}(R,b)$ *mb*	60.32 ± 1.34	55.90 ± 1.15

- **Method C: Average total and inelastic x-sections using their functional dependence on b for estimation of non-diagonal covariance term.**
- **Total x-section: α=0.23, $\chi 2$ = 8.6 →** $$\bar{\sigma}_{tot} \cdot (1+\rho^2) = 76.8 \pm 4.7 mb$$
- **Inelastic x-section: α=0.41, $\chi 2$ = 6.6 →** $$\bar{\sigma}_{in} \cdot (1+\rho^2) = 58.8 \pm 2.7 mb$$

→Poor agreement for inelastic x-section with CL=1%

→require estimation of α , which is not quoted anywhere.

Conclusion on the value of inelastic x-section

	$\overline{\sigma}_{in} \cdot (1+\rho^2)$	$\overline{\sigma}_{tot} \cdot (1+\rho^2)$
Method A	60.4 ± 2.3 mb	79.3 ± 4.2 mb
Method B	60.3 ± 2.2 mb	79.1 ± 4.0 mb
Method C	58.8 ± 2.4 mb	76.8 ± 4.3 mb

- CDF uses method A (simple average of the rate ratios)
  - ***averages actually measured numbers***
  - ***agrees with method B***
  - ***based on quoted numbers only***

$$\overline{\sigma}_{in}(B) = 59.3 \pm 2.3mb \quad \text{for } \rho = 0.135 \text{ and } @\, 1.8\ \text{TeV}$$

- D0 prefers method C (close to a median between CDF and E811)

$$\overline{\sigma}_{in}(B) = 57.7 \pm 2.4mb \quad \text{for } \rho = 0.135 \text{ and } @\, 1.8\ \text{TeV}$$

Extrapolation to 1.96 TeV

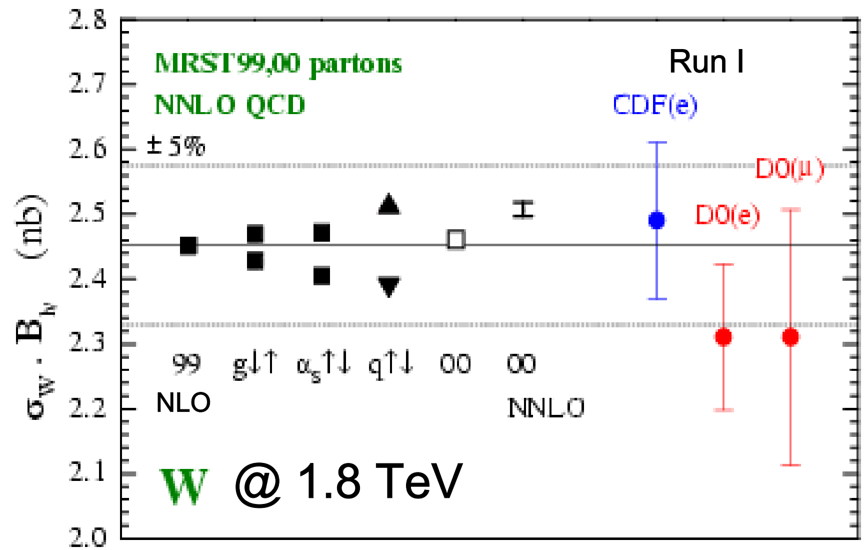
- **Energy dependence**
  - **prediction for inelastic x-section: $\sim\ln^2(s)$**
  - **prediction for diffractive x-section: $\sim\ln(s)$**
  - **E710 and E811 favor : $\sim\ln(s)$**
  - **best fit for total x-section: $\sim\ln^{2.2}s$**
- **Assuming $\ln^2(s)$ dependence and additional 1% systematic error due to uncertainty of the inelastic x-section energy dependence, the inelastic x-section at 1.96 TeV is**

add 2.4%

$$\overline{\sigma}_{in} = 60.7 \pm 2.4 mb \,@\, 1.96\ \mathrm{TeV}$$

Reference processes: W→lep,nu

- x-section @ 1.96 TeV ~2.73 nb
  with ~4% theoretical uncertainty
  (Eur.Phys.J.C14 (2000) 133-145)
  - ✓ PDF, EWK param, scale variation, higher order corrections
  - ✓ *most likely will improve in future*
- Expected rate @L=2 10^{32} ~ 0.5Hz
  - ✓ good for L normalization
- Not trivial:



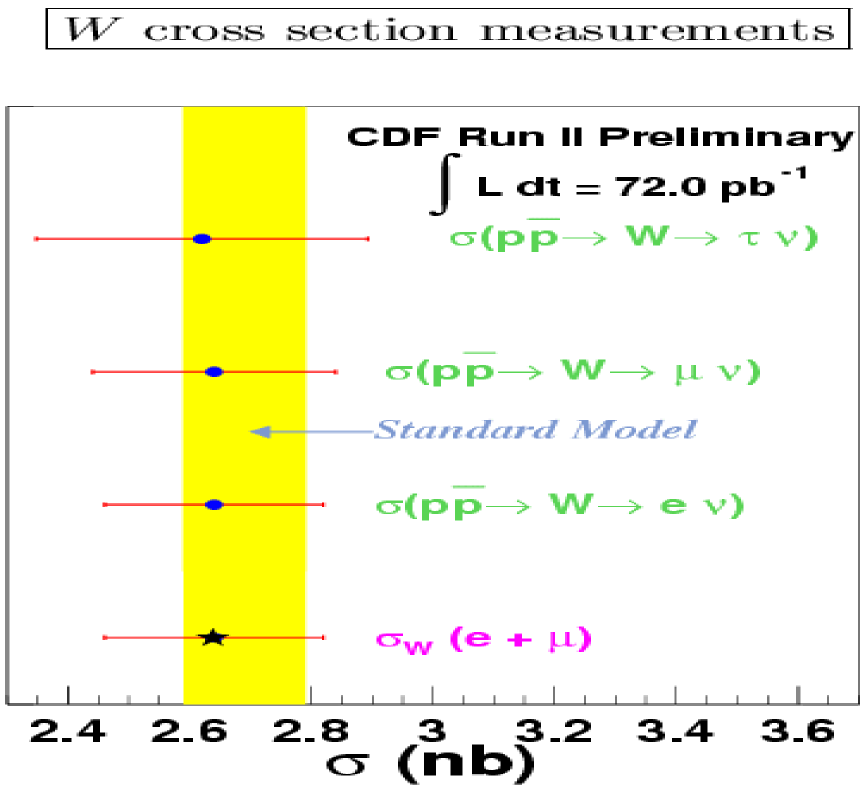
$$\boxed{N_W = L \cdot \sigma(p\bar{p} \to WX) \cdot B(W \to e\nu) \cdot \varepsilon_{\not{E}t} \cdot \varepsilon_{E_T,\eta} \cdot \varepsilon_{Trk} \cdot \varepsilon_{P_T} \cdot \varepsilon_{Iso} \cdot \varepsilon_{ID} \cdot \varepsilon_{Event} \cdot \varepsilon_{Trig}}$$

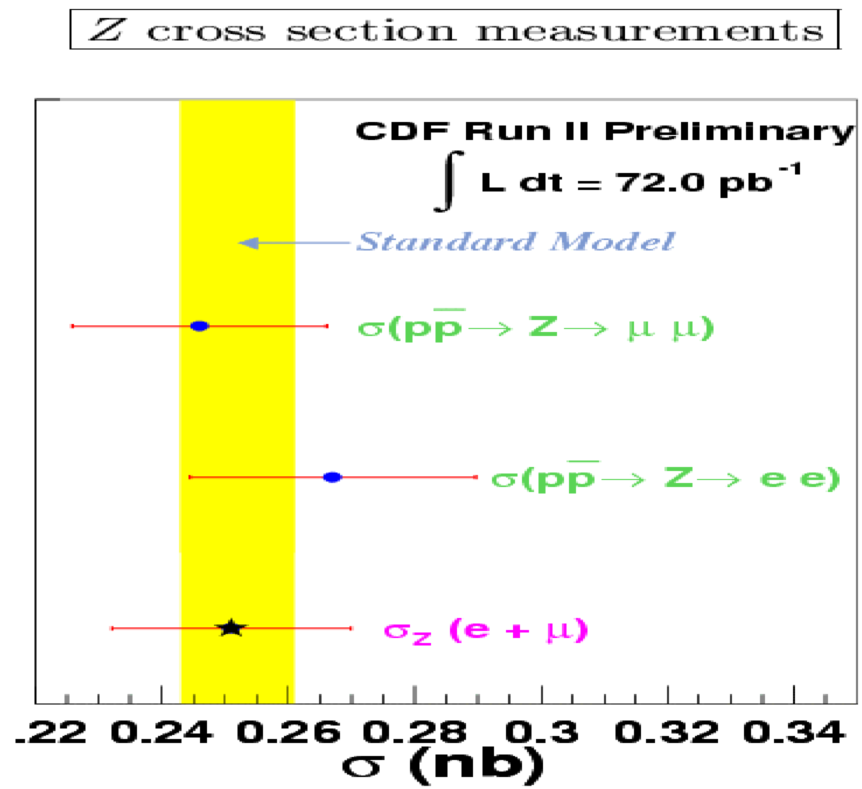
- ✓ *Trigger+selection efficiency ~25%*
- ✓ *Background: QCD, Z→ll, W→τν,..*

} → 3%-5% sys. error

δL < 5% is feasible → comparable or better than inelastic p-pbar

CDF Summary of W and Z X-Sections





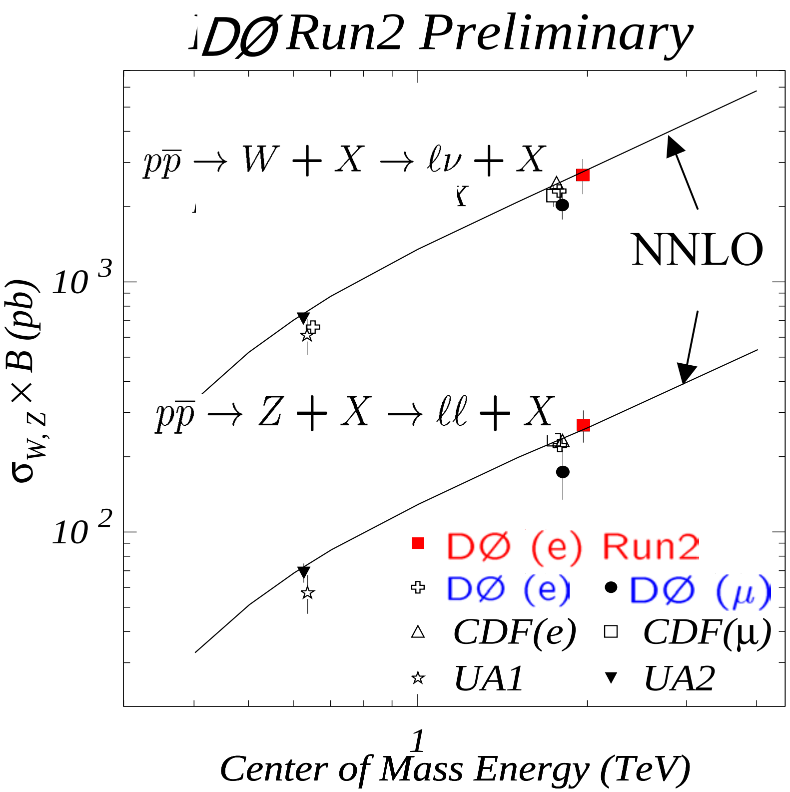
CDF Combined W and Z Cross Sections

$$\sigma_W = 2.640 \pm 0.012_{stat} \pm 0.093_{syst} \pm 0.158_{lum}\ \text{pb}$$

$$\sigma_Z = 251.5 \pm 4.3_{stat} \pm 10.6_{syst} \pm 15.1_{lum}\ \text{pb}$$

quoted $\delta L/L$ – 6%

W and Z Production Cross Section (DØ)



W Cross Section (7.5 pb-1)

$\sigma_{W \to e\nu} = 2.67 \pm 0.06\ (\text{stat}) \pm 0.33\ (\text{sys}) \pm 0.27\ (\text{lum})$ nb

quoted $\delta L/L$ – 10%

New result for Z Cross Section (31.8 pb-1)

$\sigma_{Z \to ee} = 263.8 \pm 6.6\ (\text{stat}) \pm 17.3\ (\text{sys}) \pm 26.4\ (\text{lum})$ pb

Summary

- Run I luminosity uncertainty at ~**5%** level using inelastic PPbar scattering
- In Run II two methods of luminosity measurement are available
  - *Inelastic Ppbar scattering (on-line, instantaneous, delivered,…)*
  - *W production*
  - *Yield comparable uncertainty on luminosity of ~5%*
- Expected luminosity uncertainty in Run II **below 5%** level
- CDF&DØ are working on nailing down the systematic errors
  - *Generators, Simulation, material, thresholds, etc. etc.*
  - *Agreed on value of single diffractive x-section*
  - *Still working on average inelastic x-section*